National Aeronautics and Space Administration

Ignition Susceptibility of Additive Manufactured Inconel 718® in Oxygen by Subsonic and Supersonic Particle Impact

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OVERVIEW

Parts produced by additive manufacturing (AM), particularly Selective Laser Melting (SLM), have been shown to silt metal particulate even after undergoing stringent precision aerospace cleaning processes[1]. The required pressures, temperatures, and flow rates in oxygen systems for human exploration are increasing, therefore, exacerbating the existing hazard of ignition mechanisms in these critical systems.

Particle impact (PI) ignition is the most common direct ignition source of metals in flowing oxygen-enriched environments. As the use of AM parts in oxygen systems becomes more common, their PI susceptibility must be evaluated as a critical step for evaluating the safety of current and future low-cost-high-performance engine technology and advanced environmental control and life support systems.

Ignition testing had not been previously performed on AM metals. Therefore, several randomized orthogonal design of experiment (DOE) studies were performed in the NASA White Sands Test Facility (WSTF) high-flow particle impact test system to explore the ignitability and damage susceptibility of AM Inconel 718 (IN718) subjected to subsonic and supersonic particle impact.

Many phases of experimentation were performed looking at factors such as:

- Wrought vs. SLM
- Presence or lack of hot isostatic pressing (HIP)
- Heat treatment (AMS 5664 vs. Annealing)
- Surface preparation (chemical etching, Electropolishing, electric discharge machining, mechanical polishing, rough machined surface)
- Particulate type (Aluminum, IN718 powder, Sapphire)
- Particle Velocity (Subsonic, Supersonic)
- Temperature (300-950 °F)
- Pressure (1,300 psia-4000 psia)

Mass loss of the target was measured as the response to target ignition events. Analysis of the log of mass loss resulted in the best model quality.

SELECTED OBSERVATIONS

Supersonic Particle Impact

- SLM samples that received hot isostatic pressing and electro polishing lost less mass than HIP samples with either mechanical polishing or chemical etching when impacted (Figure 1).
- SLM HIP samples lost significantly more mass than samples that were not HIP when impacted (Figure 1).
- Heat treatment and annealing was not observed to affect the ignitability of any Inconel 718 sample type.

Figure 1. Interaction of Factors

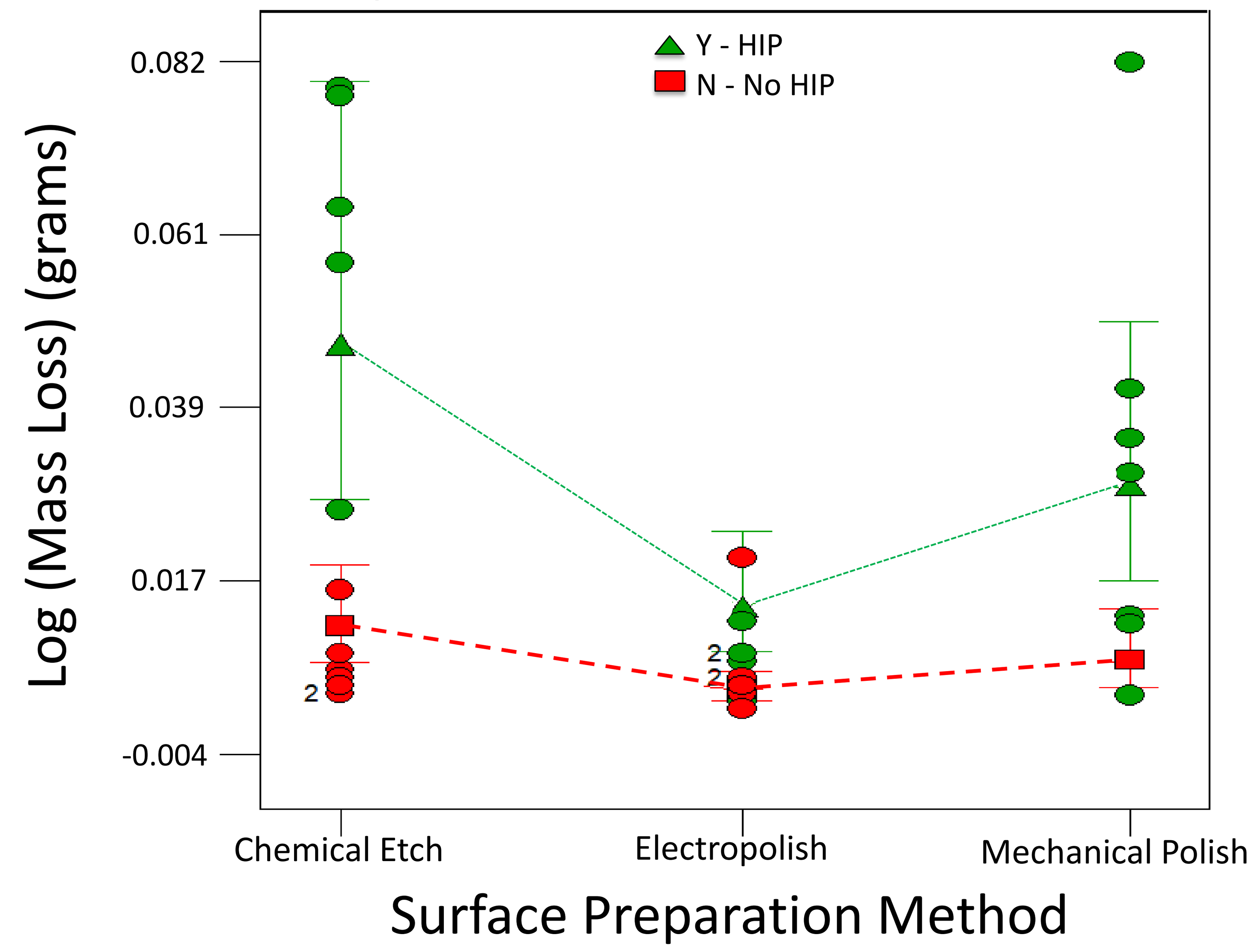

Figure 1. Results of a 30 test supersonic PI surface preparation experiment using only SLM IN718 comparing surface treatment and HIP at a static pressure of 1300 psia, and an average temperature of 562° F, and a single 200 µm aluminum ball.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	3.97	3	1.32	8.15	0.0005
A-HIP/NO HIP	*2.10*	*1*	*2.10*	*12.93*	*0.0013*
B-Etching Method	*1.60*	*2*	*0.80*	*4.93*	*0.0154*
Residual	4.22	26	0.16		
Lack of Fit	*1.01*	*1*	*1.01*	*7.86*	*0.0096*
Pure Error	*3.21*	*25*	*0.13*		
Cor Total	8.19	29			

Table 1. Analysis of variance (ANOVA) table for the experiment in Figure 1. The results indicate that both HIP processing and surface treatment are statically significant ($p<0.05$).

Subsonic Testing

- Even without ignition, SLM samples lost more mass than wrought samples. This is likely due to particle silting from the SLM samples during exposure to high flow even after aqueous cleaning.
- SLM powder is highly flammable. When contained in the subsonic particle injector, the powder ignited before injection into the flowing gas.

PARTNERSHIPS / COLLABORATIONS

NASA WSTF collaborated with the Additive Manufacturing group at NASA Marshall Space Flight Center, NASA Engineering and Safety Center, NASA Office of Safety and Mission Assurance, and NASA Glen Research Center. NASA Johnson Space Center Innovation Fund support and cost-sharing with the NASA Office of Safety and Mission Assurance allowed for this testing.

[1] N. M. Lowrey. *Potential Risks of Metal Silt Contamination in LOX/Fuel Propulsion Systems from Parts Produced by Selective Laser Melting.* ESSSA-FY16-1296, George C. Marshall Space Flight Center, Huntsville, Alabama. February 2016.

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